(12) UK Patent Application (19) GB (11) 2 378 773 (13) A

(43) Date of A Publication 19.02.2003

(21) Application No **0214891.4**

(22) Date of Filing **27.06.2002**

(30) Priority Data
(31) **10131507** (32) **02.07.2001** (33) **DE**

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(51) INT CL[7]
F02D 41/38 41/20

(52) UK CL (Edition V)
G3N NGE1 N288A N402X

(56) Documents Cited
US 6142120 A **US 5685268 A**
US 4545353 A

(58) Field of Search
UK CL (Edition T) **F1B, G3N**
INT CL[7] **F02B, F02D, F02M**
Other: **ONLINE: WPI, EPODOC, JAPIO.**

(54) Abstract Title
A method and apparatus for controlling the pressure in a high pressure fuel store

(57) The pressure in the fuel store/rail 17 is controlled by a pressure regulating valve 18. The method comprises steps to determine an individual characteristic curve (24, fig.2b) of the valve during the operation of an I C engine, and then use this curve to control the valve. The control apparatus 20 preferably receives engine parameter data such as fuel pressure 19, temperature and engine speed. Preferably stored in the memory of the controller 20 is a reference characteristic curve obtained from a plurality of such valves, with the reference curve being the statistically averaged reading (21, fig.2a). The controller may have a computer program which performs the method, whereby the individual characteristic curve is obtained by comparing specific actual engine parameter readings with those corresponding to the statistically averaged characteristic curve and adjusting the curve accordingly to determine the individual characteristic curve.

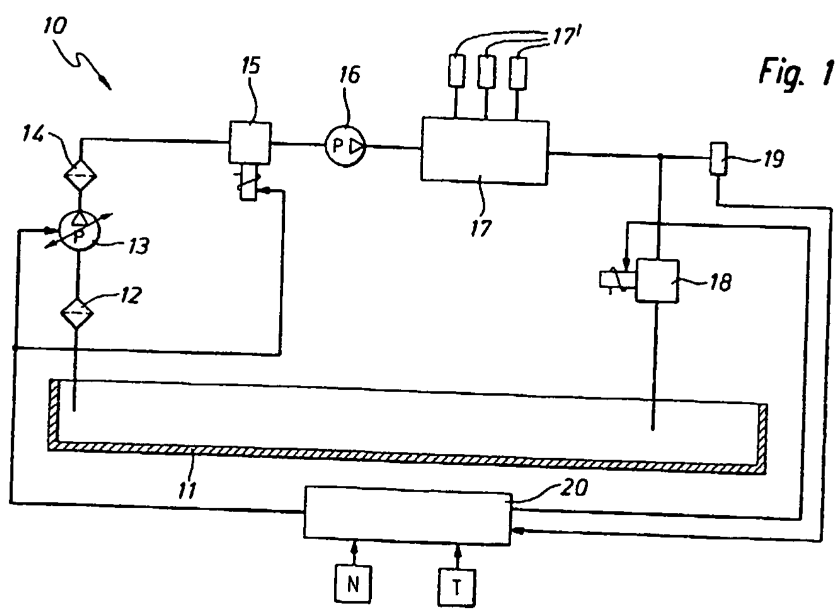

Fig. 1

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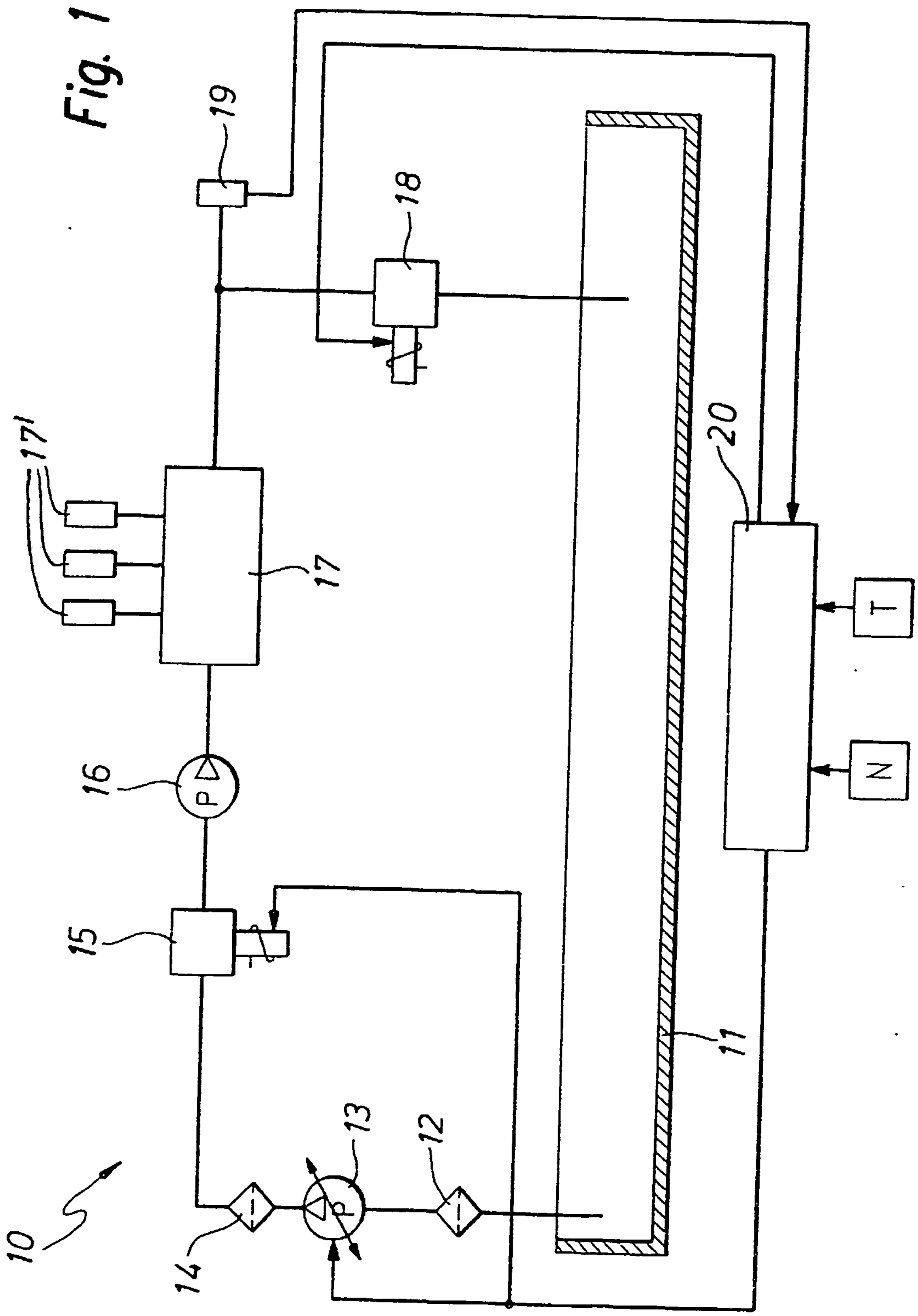

Fig. 1

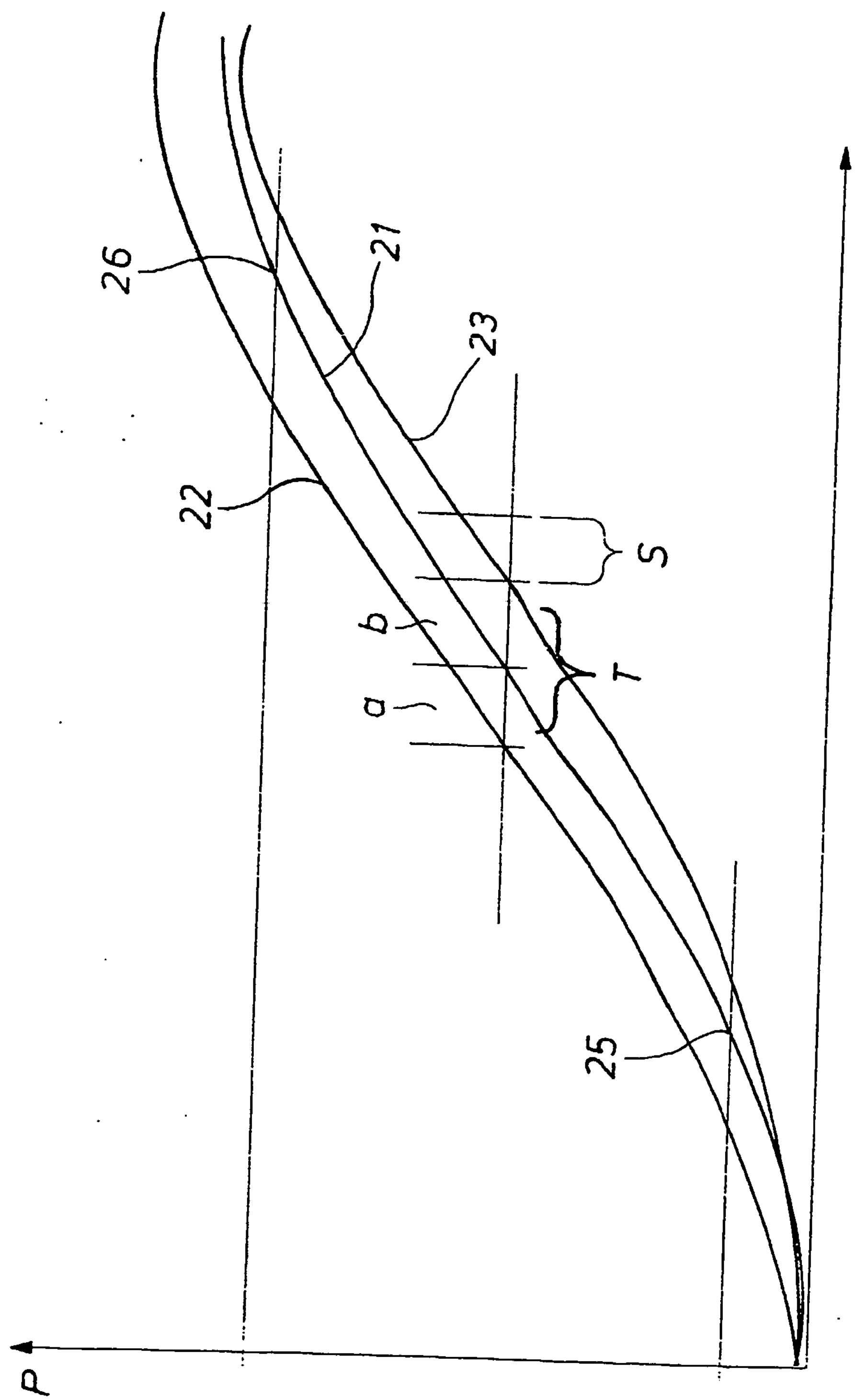

Fig. 2a

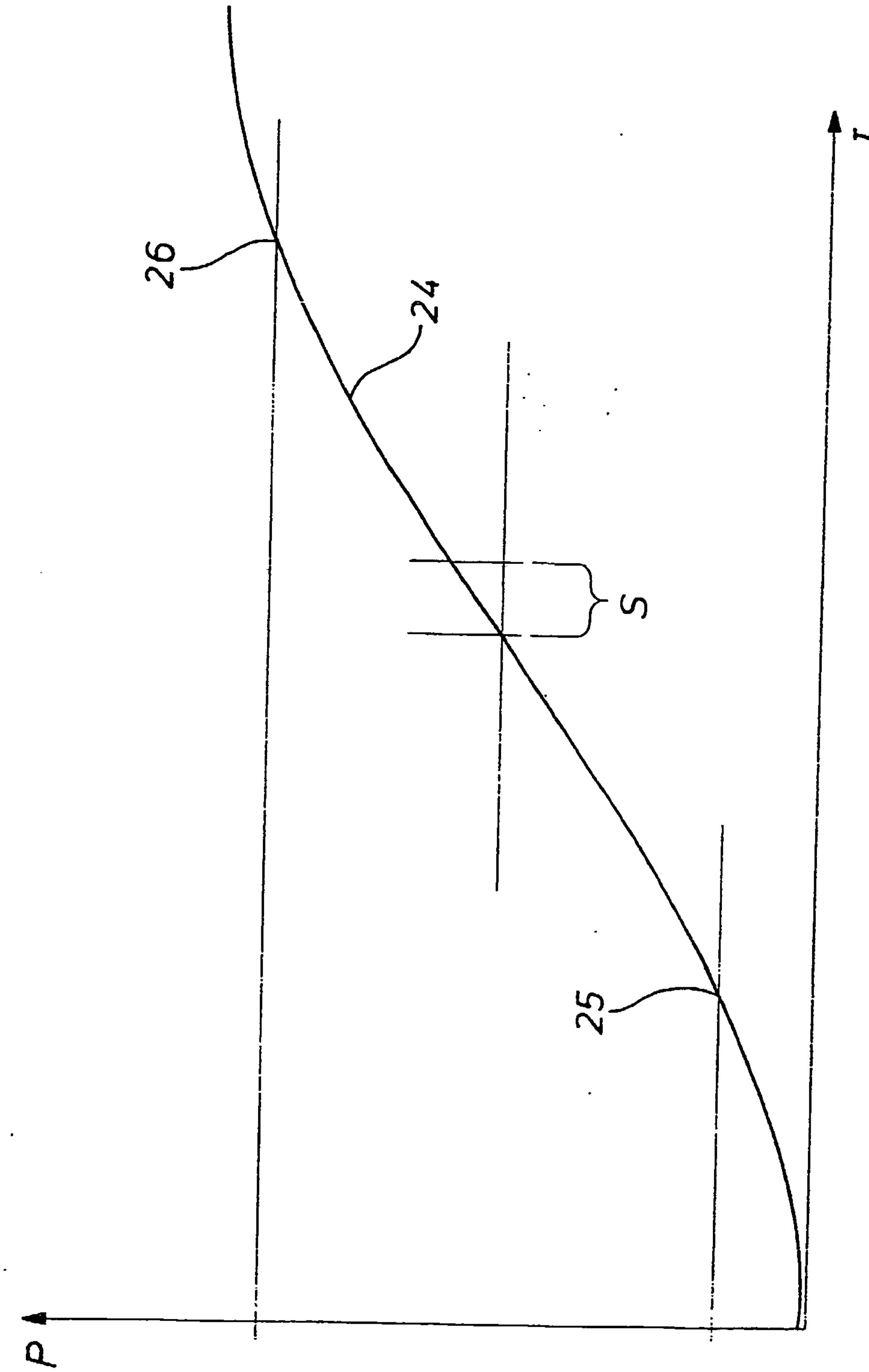

Fig. 2b

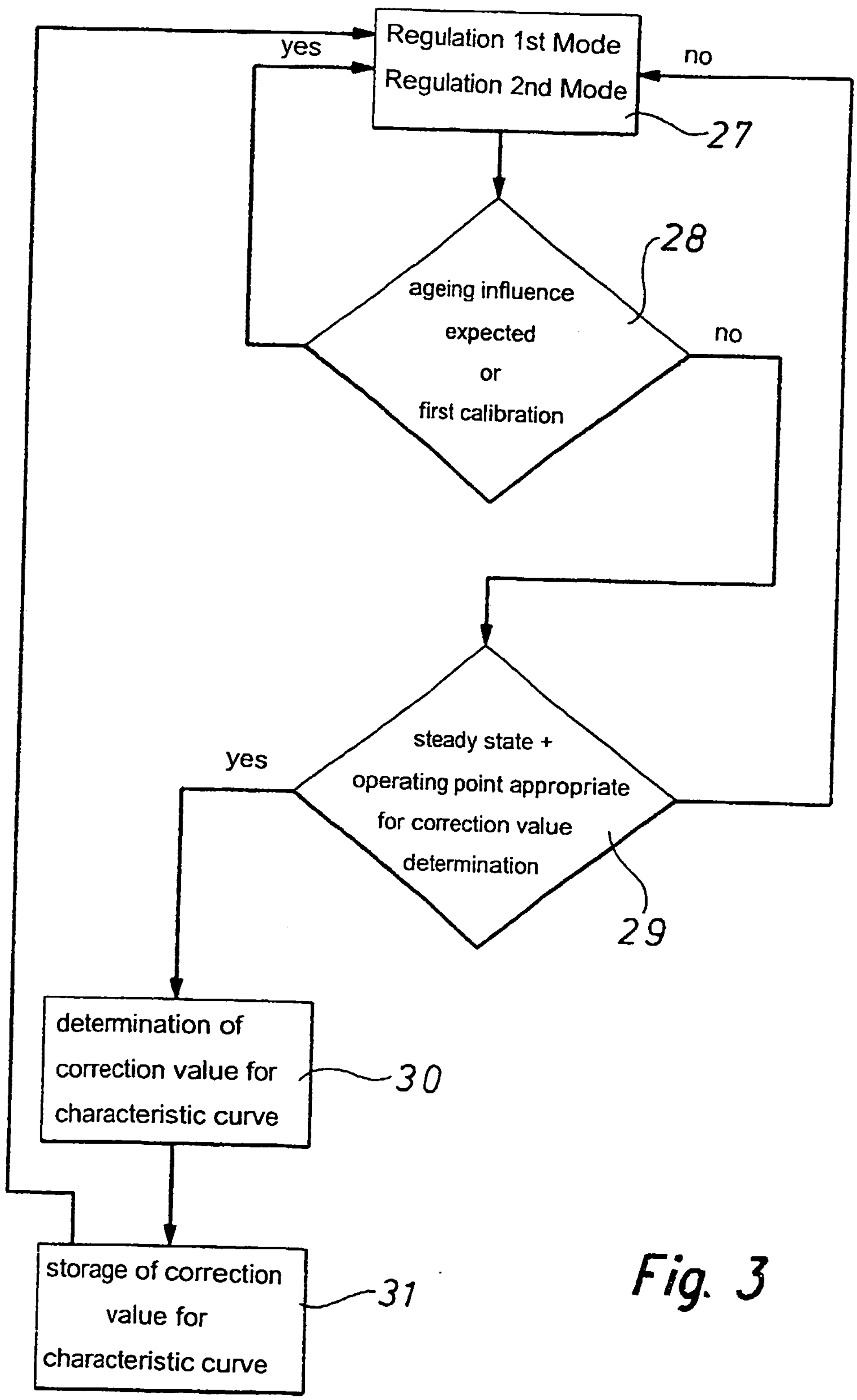
Regulation 1st Mode
Regulation 2nd Mode
27
yes
no
ageing influence expected or first calibration
28
no
steady state + operating point appropriate for correction value determination
yes
29
determination of correction value for characteristic curve
30
storage of correction value for characteristic curve
31

Fig. 3

METHOD OF AND CONTROL APARATUS FOR OPERATING AN INTERNAL COMBUSTION ENGINE

The present invention relates to a method of and control apparatus for operating an internal combustion engine, especially for a motor vehicle. The invention equally relates to an internal combustion engine equipped with corresponding control apparatus.

For the control and/or regulation of an internal combustion engine it is necessary that the behaviour of a pressure regulating valve of a fuel pressure store of the engine fuel supply system, particularly the dependence thereof on current by which the valve is controlled, is known. This is ultimately possible by ascertaining a characteristic curve of the valve.

Since, however, different pressure regulating valves usually have different characteristic curves due to production tolerances it is known to ascertain a statistically averaged characteristic curve from a plurality of such valves by measurements carried out beforehand and to utilise this, with inclusion of a tolerance range, in operation of the engine. Due to the tolerance range, however, inaccuracies result in the control and/or regulation of the engine.

There is therefore a need for a method of operating an internal combustion engine, especially of a motor vehicle, in which the production tolerances of the pressure regulating valve lead to only smallest possible inaccuracies in the control and/or regulation of the engine.

According to a first aspect of the present invention there is provided a method of operating an internal combustion engine, particularly of a motor vehicle, in which the fuel is conveyed by a high pressure pump into a pressure store and in which the pressure in the pressure store is limited by means of a pressure regulating valve, characterised in that an individual characteristic curve of the pressure regulating valve is ascertained during operation of the engine.

According to a second aspect of the invention there is provided control apparatus for an internal combustion engine, particularly of a motor vehicle, wherein in the internal combustion engine fuel can be conveyed by a high pressure pump into a pressure store and wherein the pressure in the pressure store can be limited by means of a pressure regulating valve, characterised in that an individual characteristic curve of the pressure

regulating valve can be ascertained by the control apparatus during operation of the engine.

Through the ascertaining of the individual characteristic curve of the actually used pressure regulating valve it is no longer necessary to provide the afore-mentioned tolerance range. Due to the individually ascertained characteristic curve, production tolerances no longer play a role. The entire control and/or regulation of the engine can thus be substantially more accurate.

In an advantageous development in which a statistically averaged characteristic curve is ascertained from a plurality of pressure regulating valves, the individual characteristic curve is ascertained from the statistically averaged characteristic curve. This means that initially a statistically averaged characteristic curve is derived from corresponding measurements of a plurality of pressure regulating valves. Then, during operation of the engine, the individual characteristic curve of the pressure regulating valve actually present is determined on the basis of this statistically averaged characteristic curve. The engine is then controlled and/or regulated by this individual characteristic curve.

In a first advantageous example, one point of the individual characteristic curve is ascertained in the idle running state of the engine. In a second advantageous example, one point of the individual characteristic curve is ascertained at the rated load of the engine.

In that case it is advantageous if a current in accordance with the statistically averaged characteristic curve is supplied to the pressure regulating valve and if a correction value is concluded from the deviation of, in particular, the pressure in the pressure store from a desired pressure.

In a third advantageous example, one point of the individual characteristic curve is ascertained in that operating mode in which the pressure regulating valve is used only for pressure limitation.

In that case, current for one point of the statistically averaged characteristic curve can be supplied to the pressure regulating valve, the current reduced, the pressure in the pressure store ascertained at which the pressure regulating valve opens for the first time, and a correction value concluded from this pressure.

The pressure at which the pressure regulating valve opens for the first time can be ascertained on the basis of a change in the fuel quantity fed by the metering unit to the pressure store.

It is particularly advantageous if the individual characteristic curve and/or the statistically averaged characteristic curve is or are dependent on the pressure in the pressure store and the current supplied to the pressure regulating valve.

Of particular significance is realisation of the method in the form of a computer program, which is provided for a control apparatus of an internal combustion engine, particularly of a motor vehicle. The computer program can have a program code which is suitable for the purpose of performing the method when it is executed on a computer. Moreover, the program code can be stored on a computer-readable data carrier, for example a so-called flash memory. In this case, the method is thus realised by the computer program.

Examples of the method and embodiments of the control apparatus of the present invention will now be more particularly described with reference to the accompanying drawings, in which:

Fig. 1 is a schematic block circuit diagram of an internal combustion engine equipped with control apparatus embodying the invention;

Fig. 2a is a schematic diagram of a characteristic curve of a pressure regulating valve of prior art control apparatus;

Fig. 2b is a schematic diagram of a characteristic curve of a pressure regulating valve of the control apparatus of Fig. 1; and

Fig. 3 is a schematic flow chart of the steps of a method exemplifying the invention, for ascertaining the characteristic curve according to Fig. 2b.

Fig. 1 shows a fuel supply system 10 of an internal combustion engine. The fuel supply system 10 is usually also termed a common rail system and is suitable for direct injection of fuel under high pressure into the combustion chambers of the engine.

The fuel is sucked from a fuel tank 11 by way of a first filter 12 by a pre-conveying pump 13. The pump 13 can be, for example, an electric fuel pump.

The fuel inducted by the pre-conveying pump 13 is conveyed by way of a second filter 13 to a metering unit 15. The metering unit 15 can be, for example, an electromagnetically controlled proportioning valve.

A high-pressure pump 16 is arranged downstream of the metering unit 15. A mechanical pump driven by the engine is usually used as the high-pressure pump 16.

The pump 16 is connected with a pressure store 17, which is frequently also termed rail. This pressure store is disposed in communication with injection valves 17' by way of fuel ducts. The fuel is injected into the combustion chambers of the engine by way of the injection valves 17'.

A pressure regulating valve 18 is connected at an outlet side with the fuel tank 11 and at an inlet side with the pressure store 17. The pressure regulating valve 18 can be, for example, an electrically controllable electromagnetic valve.

In addition, the fuel supply system includes a pressure sensor 19, which is coupled with the pressure store 17, and control apparatus 20, which is acted on by a plurality of input signals. These input signals can be the rotational speed N or the temperature T of the engine. Equally, the signals can include the pressure within the fuel store 17, as measured by the pressure sensor 19.

The control apparatus 20 generates a plurality of output signals in dependence on the input signals. The output signals can be, for example, a signal for drive control of the pump 13, a signal for drive control of the metering unit 15 and a signal for drive control of the pressure regulating valve 18.

In operation of the fuel supply system 10 as illustrated in Fig. 1, fuel in the tank 11 is inducted by the pump 13 and conveyed to the metering unit 15. The pressure in this region of the system 10 is usually in the region of about 1 bar to about 3 bar. This region is accordingly also termed low-pressure region, which can be monitored or controlled and/or regulated with the help of a further valve (not illustrated in Fig. 1).

The metering unit 15 passes on to the high-pressure pump 16 that quantity of fuel which - depending on the instantaneous operational state of the engine - is to be injected into the engine combustion chambers by way of the injection valves 17'. From the high-pressure pump 16 the fuel to be injected is then conveyed into the fuel store 17 in order to be supplied from there for injection by way of the injection valves 17' into the associated combustion chambers.

In the afore-described mode of operation of the engine the pressure regulating valve 18 is used for pressure limitation. This means that the valve 18 is controlled in such a manner that it opens at a predetermined pressure in the pressure store 17. Thus, an increase in the pressure in the pressure store above the predetermined value is prevented.

The metering of the fuel by way of the metering unit 15 is possible only conditionally, particularly in the case of low fuel temperatures. The metering unit 15 is then controlled in such a manner that full conveying takes place, i.e. the pump 16 conveys - in correspondence with its characteristic curve - the respective maximum fuel quantity into the fuel store 17.

In this mode of operation the fuel quantity to be injected is influenced in the manner that the pressure in the pressure store 17 is controlled and/or regulated. For this purpose the pressure regulating valve 18 and the pressure sensor 19 are utilised.

As described, the valve 18 is also used for pressure limitation. In this mode of operation, as also already mentioned, the valve 18 is controlled in such a manner that it opens only at the predetermined value of the pressure in the pressure store 17. In order for the pressure regulating valve 18 to be correctly controlled in drive, the characteristic curve thereof is of significance.

A characteristic curve 21 of the pressure regulating valve 18 is illustrated in Fig. 2a, in which pressure P is recorded over current I. The pressure P is the pressure in the pressure store 17 and the current I is that current by which the control apparatus 20 controls the pressure regulating valve 18.

The characteristic curve 21 is a statistically averaged curve ascertained from actual measurements of a plurality of pressure regulating valves. The pressure P at changing

current I was thus measured for these valves in order to calculate therefrom the characteristic curve 21 as a statistical mean value.

Due to production tolerances, as also due to other influences, the actual characteristic curve of a specific pressure regulating valve differs from the characteristic curve 21 of Fig. 2a, since this - as mentioned - represents only a statistical mean curve of a plurality of valves. This difference of the actual characteristic curve of a specific pressure regulating valve from the characteristic curve 21 of Fig. 2a is taken into consideration by provision, as shown in Fig. 2a, of a tolerance region T. This tolerance region T consists of regions a and b at both sides of the characteristic field 21. There thus results the tolerance range T which is established by the boundary characteristic curves 22 and 33.

As already explained, the pressure regulating valve 18 of Fig. 1 is also used for pressure limitation. In this mode of operation it is necessary that the pressure regulating valve 18 remains reliably closed until attainment of the particular value at which the valve 18 is to open.

Due to tolerances of different pressure regulating valves the possibility exists that the actual characteristic curve of one of these valves corresponds with the boundary characteristic curve 23 of Fig. 2a. In order to ensure that the pressure regulating valve 18 remains closed until the desired value at which it is to open, a safety region S is provided in Fig. 2a. This safety region S adjoins the boundary characteristic curve 23. In addition, it should be noted that the valve 18 is open when the current I goes towards zero and closed when the current is increased.

If the pressure regulating valve 18 is used for pressure limitation, the desired value at which the valve is to open is set in such a manner that, according to Fig. 2a, initially the current I associated with the desired value above the characteristic curve 21 is ascertained in order to then ascertain the tolerance range T connected with this current I and to subsequently add the relevant safety region S to the boundary characteristic curve 23 resulting therefrom. Thus, according to Fig. 2a, initially the region b of the tolerance range T is added to the characteristic curve 21 and thereafter the safety region S is added. The current I ascertained from this calculation is then set at the valve 18.

The disadvantage of the manner of procedure described in connection with Fig. 2a is that due to the tolerance range T a relatively large inaccuracy in the setting of the current I

arises. This inaccuracy can, for example, lead to problems when the valve 18 is used for pressure limitation. In particular, it is possible that the valve 18 in this mode of operation opens much too late, thus when the pressure in the pressure store 17 is too high. The pressure at which the valve 18 is to open can be, for example, 1600 bar and the tolerance range T and/or the safety range S can each be about 200 bar.

A further characteristic curve 24 of the pressure regulating valve 18 is illustrated in Fig. 2b, in which pressure P is again recorded over current I. The pressure P is the pressure in the pressure store 17 and the current I is that current by which the valve 18 is controlled by the control apparatus 20.

The characteristic curve 24 is a statistically averaged and subsequently individually corrected characteristic curve for a specific pressure regulating valve. To that extent the characteristic curve 24 of Fig. 2b is based on the characteristic curve 21 of Fig. 2a.

However, by contrast to Fig. 2a the characteristic curve 24 of Fig. 2b has been subjected to a correction. It is essential in this embodiment that the starting point of the characteristic curve 24, thus the characteristic curve 21 of Fig. 2a, is a statistically averaged characteristic curve which has been ascertained from a plurality of actually measured pressure regulating valves and that, by contrast, the characteristic curve 24 is an individual characteristic curve which has validity only for a specific pressure regulating valve. This results from the fact that the correction has been undertaken on the basis of a specific regulating valve and is thus applicable only to that valve.

The starting point of the characteristic curve 24 of Fig. 2b is - as stated - the statistically averaged characteristic curve 21 of Fig. 2a. In operation of the engine of Fig. 1, the correction is now undertaken for the pressure regulating valve 18 present in the system 10. The correction of the characteristic curve 21 is undertaken in that mode of operation in which the metering unit 15 is fully open and in which the metering of fuel is controlled and/or regulated by way of the pressure regulating valve 18 with the help of the pressure sensor 19.

For that purpose the engine is operated at a first point of the characteristic curve 21. This point can be, for example, the idling state of the engine. In the idling state of the engine relatively little fuel is to be injected into the engine combustion chambers. This means that when the metering unit 15 is fully open a relatively large amount of fuel has to be

conducted back to the fuel tank 11 by way of the valve 18. The valve 18 must therefore open relatively widely. This is synonymous with a relatively low pressure present in the store 17. The idling state of the engine can accordingly be achieved, by way of example, at the point 25 in Figs. 2a and 2b.

As mentioned, there is now assimilation of engine operation to this first point 25 on the characteristic curve 21 of Fig. 2a. For this purpose, the valve 18 is acted on by the associated current I. This has the consequence of a specific pressure P according to the characteristic curve 21 of Fig. 2a. Due to this pressure in the pressure store 17, a specific fuel quantity is injected by way of the injection valve 17' into the combustion chambers. This then has the consequence of a specific rotational speed of the engine.

The pressure in the pressure store 17 is now controlled and/or regulated in such a manner that a desired pressure is set in the pressure store 17. From this influencing of the pressure in the pressure store 17 there is then ascertained a correction value which is utilised for correction of the characteristic curve 21. This correction value is stored.

Preferably the I component of the pressure regulator for the pressure in the pressure store 17 is utilised as a value of the deviation of the specific pressure regulating valve from the characteristic curve 21 of Fig. 2a, in order to then form the correction value therefrom.

In corresponding manner the same method is then performed at a second point 26. This second point can be, for example, the rated load of the engine. At this rated load of the engine a considerable amount of fuel has to be injected into the combustion chambers. When the metering unit 15 is fully opened, relatively little or even no fuel has to be conveyed back by way of the valve 18 to the tank 11. The pressure regulating valve 18 thus has to be almost or even completely closed. This is achieved in the manner that the current I by which the valve 18 is controlled is high. This then leads, according to the characteristic curve of the valve 18, to a large pressure P. This large pressure in the pressure store 17 then has the consequence that a large fuel quantity is injected into the combustion chambers by way of the injection valves 17'.

There is now assimilation of engine operation to the second point 26. The pressure in the pressure store 17 is thereupon controlled and/or regulated in such a manner that a desired pressure is set. From this influencing of the pressure in the pressure store 17 there is then

in turn ascertained a correction value which is utilised for correction of the characteristic curve 21.

This correction takes place in the same manner as already described. There is thus stored a correction value which ultimately corresponds with the deviation of the specific pressure regulating valve 18 from the characteristic curve 21.

In a given case it is possible to assimilate engine operation to further points on the characteristic curve 21 and undertake, in each instance, the afore-described procedure. In this manner several correction values can be ascertained.

As a result, the characteristic curve 24 of Fig. 2b for the specific pressure regulating valve 18 can now be ascertained on the basis of the characteristic curve 21 of Fig. 2a and the correction values determined for that valve in the context of the particular engine with which it is associated. This characteristic curve 24 is to that extent the characteristic curve 21 corrected with the help of the ascertained correction values.

In that region in which the pressure regulating valve 18 is almost completely closed, thus in which particularly small quantities of fuel can flow through the valve 18, the possibility exists that the characteristic curve 21 exhibits non-linearities. In that case, it is possible that these non-linearities cannot be corrected, or at least not corrected sufficiently accurately, by the described procedure. For this purpose a further procedure is provided, which is oriented particularly to correction of possible non-linearities of the characteristic curve 21 in the region of small throughflow quantities of the valve 18.

In the case of this procedure the engine is operated in that mode of operation in which the pressure regulating valve 18 is used only for pressure limitation. The fuel quantity which is to be metered is controlled and/or regulated in this mode of operation by means of the metering unit 15.

The engine is now operated in a region of the characteristic curve 21 in which the valve 18 is reliably closed. The current I through the valve 18 is thus selected to be of such a size that the valve in all cases does not let through any fuel.

The current I to the pressure regulating valve 18 is thereafter reduced. This has the consequence that the pressure P, which the valve 18 can withstand, is progressively

smaller. If this pressure P now attains that pressure which is present in the pressure store 17 of the engine this then has the consequence that the pressure regulating valve 18 opens at least slightly when there is a further reduction in the current I. This opening results from the fact that due to the further reduction in the current I, the pressure in the pressure store 17 is greater than the pressure which is associated with the reduced current I and which the pressure regulating valve 18 can withstand.

Insofar as the engine in the afore-described method is disposed in a steady or stationary state then the slight opening of the pressure regulating valve 18 has the consequence that the metering unit 15 has to meter more fuel in order to maintain this state. This change in the metering of fuel by the metering unit 15 can then be utilised for the purpose of undertaking a correction of the characteristic curve 21 of Fig. 2a. In particular, a conclusion can be made by way of the characteristic curve 21, from the current I which at that instant acts on the valve 18, about the associated pressure P. This pressure P can then be compared with that pressure in the pressure store 17 which is measured, for example, with the help of the pressure sensor 19. There can then be ascertained from the difference a correction value which brings the pressure P ascertained by way of the characteristic curve 21 and the pressure, which is measured with the help of the pressure sensor 19, in the pressure store 17 into agreement. This correction value can in turn be stored and be used for ascertaining the characteristic curve 24 of Fig. 2b.

In this manner it is possible to calculate the characteristic curve 24 of Fig. 2b relatively accurately over the entire course thereof.

As already mentioned, the characteristic curve 24 is a characteristic curve which is associated with an individual pressure regulating valve 18. By virtue of this individuality of the characteristic curve 24 it is no longer necessary to provide a tolerance range T as was present in Fig. 2a. This tolerance range T can be dispensed with without replacement.

Thus, it is only still necessary to provide the safety region S and to add the individual values of the characteristic curve 24. If the individual characteristic curve 24 associated with the pressure regulating valve 18 of the engine of Fig. 1 has been ascertained in the described mode and manner it is thereafter only necessary in operation of the engine to additionally take into consideration the safety range S. If the engine is thus operated in, for example, the mode in which the valve 18 is used only for pressure limitation, then it is sufficient if only the safety range S is additionally added to the desired value to which the

valve shall be set. A tolerance range does not have to be taken into consideration. The entire control and/or regulation of the engine is, due to the tolerance range no longer having to be taken into consideration, substantially more accurate.

In Fig. 3 the described method for ascertaining the characteristic curve 24 of Fig. 2b is illustrated on the basis of a flow chart.

A step 27 represents the starting point of the method sequence. The starting point can be that mode of operation in which the metering unit 15 is fully open and the control and/or regulation of the fuel quantity, which is to be injected, is carried out with the help of the pressure regulating valve 18. This is termed 'Regulation 1st Mode' in Fig. 3. Alternatively, the starting point can be that mode of operation in which the pressure regulating valve 18 is used only for pressure limitation. This mode of operation is termed 'Regulation 2nd Mode' in Fig. 3.

In a step 28 it is checked whether due to the total operating time of the engine an ageing influence is to be expected or whether there is concerned a first calibration of the engine. If one of these two cases is present, then the described method is not carried out and a return is made to step 27. If neither of these cases is present, then the method is continued with a step 29.

In the step 29 it is checked whether the engine is disposed in a steady state and at an operating point of the characteristic curve 21 of Fig. 2a at which a correction value is to be determined. If this is not the case, the method is not continued and a return to step 27 is again made. If, however, this is the case, then in a step 30 the correction value associated with the operating point of the characteristic curve which is reached is ascertained. In a step 31 the calculated correction value is then stored in a store of the control apparatus 20.

This method sequence of Fig. 3 is performed several times in each of the first mode and the second mode and, in fact, until a sufficient number of correction values are present in order to ascertain the characteristic curve 24 of Fig. 2b. Thereafter, the engine is controlled and/or regulated in the two operating modes with the help of the characteristic curve 24 of Fig. 2b.

CLAIMS

1. A method of operating an internal combustion engine supplied with fuel by way of a high-pressure fuel store in which the pressure is influenced by a controllable pressure-regulating valve, the method comprising the steps of determining an individual characteristic curve of the valve during operation of the engine and utilising the determined curve in control of the valve.

2. A method as claimed in claim 1, wherein the individual characteristic curve is based on a statistically averaged characteristic curve ascertained from a plurality of such valves.

3. A method as claimed in claim 2, wherein the step of determining comprises establishing a specific point of the individual curve when the engine is in its idling state.

4. A method as claimed in claim 2 or claim 3, wherein the step of determining comprises establishing a specific point of the individual curve when the engine is operating at its rated load.

5. A method as claimed in any one of claims 2 to 4, wherein the step of determining comprises supplying energy to the valve for control thereof in accordance with the averaged curve and ascertaining a correction value for the averaged curve in dependence on a detected deviation in an operating parameter of the engine.

6. A method as claimed in claim 5, wherein the deviation is the difference between the pressure in the store and a predetermined pressure.

7. A method as claimed in any one of the preceding claims, wherein the step of determining comprises establishing a specific point of the individual curve when the valve is disposed in a mode exclusively for limitation of the fuel store pressure.

8. A method as claimed in any one of the preceding claims, wherein the step of determining comprises supplying energy to the valve for control thereof at a specific point of the averaged curve, reducing the supplied energy until the fuel store pressure causes the valve to open and ascertaining a correction value for the averaged curve in dependence on the value of the fuel store pressure at which the valve opened.

9. A method as claimed in claim 8, comprising the step of detecting said fuel store pressure value in dependence on a detected change in a fuel feed quantity fed to the store.

10. A method as claimed in any one of the preceding claims, wherein the curve or at least one of the curves, as the case may be, is dependent on the fuel store pressure and on the level of energy supplied to the valve for control thereof.

11. A computer program for control apparatus of an internal combustion engine, the program having a code to cause computer means of the apparatus to perform the method of any one of the preceding claims.

12. A program as claimed in claim 11, wherein the code is stored on a computer-readable data carrier.

13. Control apparatus for controlling operation of an internal combustion engine supplied with fuel by way of a high-pressure fuel store in which the pressure is influenced by a controllable pressure-regulating valve, the apparatus comprising means for determining an individual characteristic curve of the valve during operation of the engine and means for utilising the determined curve in control of the valve.

14. Apparatus as claimed in claim 13, wherein the apparatus includes a computer controlled by a program code of a program to determine and utilise the individual curve.

15. An internal combustion engine provided with a high-pressure fuel store for fuel to be supplied for combustion in the engine, with a controllable pressure-regulating valve for influencing pressure in the store and with control apparatus for determining an individual characteristic curve of the valve during operation of the engine and utilising the determined curve in control of the valve.

16. An engine as claimed in claim 15, wherein the engine is a motor vehicle engine.

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Application No:	GB 0214891.4	**Examiner:**	Tyrone Moore
Claims searched:	1-16	**Date of search:**	4 December 2002

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
A	-	US 5685268	(SIEMENS AUTOMOTIVE CORP) See figure 1, item 40, 41 and the description in columns 4, 7 and 8.
A	-	US 4545353	(ROBERT BOSCH GMBH) See figures 1-6 and the description in column 2 at lines 44-65.
A	-	US 6142120	(ROBERT BOSCH GMBH) See figures 1-2 and the description.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^T:

G3N; F1B

Worldwide search of patent documents classified in the following areas of the IPC^7 :

F02B; F02D; F02M.

The following online and other databases have been used in the preparation of this search report :

WPI, EPODOC, JAPIO.